LANDFILL HYDROGEOLOGY - PROVISIONAL ABSTRACTS

Keynote: Landfill Hydrogeology – impacts and challenges

William Powrie, School of Civil Engineering and the Environment, University of Southampton

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Protecting Groundwater from Landfill - Environment Agency Groundwater Policy

Mark Morton, Environment Agency

The Environment Agency has overall responsibility for regulation of waste activities. These activities cover landfill, incineration, transfer stations, waste storage and treatment. Waste management as a potentially polluting activity is tightly controlled by legislation. The primary regulatory tools are Pollution Prevention and Control permits and Waste Management Licences. Before a permit or licence is issued a site must have valid planning permission.

Development planning and permissions are controlled by planning legislation and are the responsibility of local planning authorities. The location of waste management facilities and disposal sites in particular is a key element of their design. For this reason our policy for landfill in particular is focused on landfill location.

Suitable sites for landfill are becoming scarce due to legislation change and the need to protect groundwater. Further changes in legislation may also affect landfill development. New proposed environmental permitting regulations bring together pollution prevention and control and waste management licensing. The Water Framework Directive and Groundwater Daughter Directive may make some minor changes to how we interpret discharges to groundwater from landfill. These changes will enhance the risk based approach to site assessment.

One of the most pressing issues is dealing with 'closed 'dilute and disperse landfills This applies to 'closed' sites and the problem of active sites with 'closed' unlined cells and the possibility of 'piggybacking'.

Key Issues

- The disposal of waste into landfill is a major potential hazard to groundwater quality. Unless the whole of the waste mass is inert, landfills represent a store of pollutants some of which will inevitably find their way into the environment.
- To reduce the risk to groundwater our policy is to direct landfill to areas where the risk of groundwater pollution is minimised and to avoid the situation where the development of a groundwater resource is constrained by the presence of a landfill. This will ensure the groundwater resource is available for future generations.

In summary the objectives of the policy on landfill location are:

- to ensure that in vulnerable areas, groundwater protection measures will be viable for the entire duration of the pollution risk from landfilling;

- to provide a framework giving risk-based advice to waste planning authorities (WPAs) and developers. The aim is to steer development into less sensitive locations and to facilitate WPA compliance with their statutory role under the Landfill Directive.

Studies on Landfill Recirculation Hydrology at Beddington Landfill

Keith Knox, Knox Associates

In a study running from July 2000 to January 2006 (Knox and Shaw, 2006), a grid of 20 vibrating wire piezometers was installed in the ~1ha base of a new landfill cell. The cell was then filled within ~1 year to a maximum depth of ~25m and clay-capped. That phase of the study provided information on:

- *Lag times for rainfall infiltration events to reach the site base through increasing depths of waste, during infilling.* The lag time for infiltration events in the range 20 to 50mm to reach the base of uncapped wastes started at less than 12 hours for 2m of MSW. The response time increased to ~2 days by the time there was 5m of waste. Once the waste depth had reached ~9m, events of this size produced no discrete response at the base of the wastes, but led instead to a prolonged slow rate of drainage to the base.

- *Information on the drainable porosity of wastes at the base of the cell.* Drawdown from leachate abstraction produced estimates of the rapidly drainable porosity for fresh MSW at depths up to a maximum of ~25m, ranging from 2.5 to 6.5%v/v (mean ~4.6%v/v).

- *Information on the quantity of leachate held 'in transit' during steady state recirculation.* The study showed that while abstraction continued, basal heads declined or remained steady, regardless of whether the abstracted leachate was discharged off site or re-injected. When abstraction was suspended, heads increased. This 'drain-down' continued for periods of up to at least 48 days, with total increases in leachate head of up to 2.1m

Subsequent work (Environment Agency, 2007; White et al, 2007) has modelled the drain down of leachate, providing confirmation of the limited lateral spread (10 to 15m) when leachate is recirculated via a linear sub-cap structure such as a tyre-filled trench.

In the most recent phase of the study, three shallow injection wells have been installed through the clay capped cell. Two were drilled into an existing tyre-filled 30m long sub-cap trench and the third directly into wastes, at ~10m from the trench.

An experiment to inject ~500m^3 of leachate during a short period (~2 weeks) is planned for the later part of 2007. This quantity has been selected to be enough to generate a significant head rise (~0.5m). Leachate will be injected under slight pressure, provided by linking each well head to a bowser that will act as a header tank.

Results of this trial and any further work will be presented in the paper. The trial will also provide information on the injection rates achievable with shallow wells.

Hydrogeological Impact of Landfill Surcharging

Nick Rukin, Entec UK Ltd

With waste settlement rates in many non-inert landfills turning out to be greater than anticipated when planning permission was granted, operators are frequently seeing the need to place new waste over older waste to ensure appropriate landforms for landscape and cap drainage purposes. Commercially, surcharging of existing Landfill Directive compliant cells provides revenue from the additional waste without the costs associated with cell base construction. There are therefore both technical needs and commercial drivers for surcharging.

Surcharging by its nature increases the thickness of waste and, in terms of landfill hydrogeological issues, this in turn:

- reduces the drainable porosity of the existing waste, which leads to increased leachate levels if unmitigated;
- reduces the permeability (hydraulic conductivity) of the deeper waste which means the yields of retrofit wells are likely to reduce and with this potentially comes a need for more wells spaced more closely together than pre-surcharging;
- leads to a deterioration in leachate quality with acetogenic leachate from newer waste being added to perhaps more dilute, older, methanogenic leachate;
- extends the estimated time for waste stabilisation for that cell, although may bring this stabilisation timescale closer to that of more recent cells and so not affect PPC Permit surrender dates;
- provides new absorptive capacity.

This talk discusses the results from three studies which have aimed to quantify these effects.

Mapping Contamination by Landfill Leachates Using CFCs In Groundwater and Rivers

Tim Atkinson[1,2], Y Zhao[1], A.Bateman[2] & A.Foley[1]
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Landfills are powerful sources of Chlorofluorocarbon compounds (CFCs) that had uses as refrigerants, aerosol propellants and foam insulating gases, and were disposed along with the waste materials containing them. Landfill gases contain concentrations of CFC11, CFC12 and CFC 113 that are up to thousands of times higher than in the atmosphere. These gases partially dissolve in leachate, producing concentrations which are ~1000 times higher than would be produced by dissolution of atmospheric gas alone. Uncontaminated groundwaters and rivers have CFC concentrations which are either in equilibrium with the current atmosphere, or lower than this level. This great disparity between leachate and uncontaminated waters offers a means of using CFCs as tracers of environmental contamination by landfill leachate, through systematic survey of groundwater and river water samples around a site. The threshold at which diluted leachate can be detected is around 0.1-1%, compared with 10-50% for conventional indicators such as COD, Cl^-, Fe^{3+} or NH_4^+. A single, systematic survey can establish the extent and pattern of a leachate plume, whereas conventional indicators must rely on monitoring continued over many years to establish rising trends above background.

Three case studies from landfills in East Anglia and one in Yorkshire are described. Two active landfills were shown to be contaminating nearby water courses with CFCs diluted to <1% of their original concentration in leachate. Two old, closed, dilute-and-disperse sites had CFC plumes that could be mapped in groundwater samples and shown to contaminate nearby streams. The active landfills produced ratios among the three CFCs in groundwater which closely matched those in landfill gases and leachates, effectively "finger-printing" their source. CFCs from old landfills showed more complex behaviour, with selective decomposition of CFC11 in the reducing conditions within leachate contamination plumes, and selective release of CFC11 into the gas phase in the unsaturated zone of the ground around each site.

Tritium as a Specific Indicator of Contamination from Landfill Leachate?

Howard Robinson, Enviros

Since publication of the Environment Agency's detailed report on the Composition of Leachates at UK Landfill Sites in 1996, the isotope tritium has been widely recognized to be present at relatively high concentrations in landfill leachates, compared to levels typically found in other environmental samples. The fact that high tritium levels are so common in leachates, means that tritium has potential to be an ideal indicator of contamination that originates specifically from landfills. Data will be provided to demonstrate the value of such determinations.

To date, it has not been possible to convincingly identify the source of tritium in landfilled municipal solid waste, although several papers have suggested that specific components of waste streams may be responsible, such as cinema exit signs and other similar "gaseous tritium light sources". Data are however far from conclusive. The author will discuss the science of tritium as a tracer, and by reference to data from South African landfill sites, including many in very rural areas which are unlikely to receive such waste streams, will cast doubt on such simplistic explanations. He will also present data from a large UK dilute and attenuate landfill, where very sensitive tritium data provide the only indication of any impact on receiving waters, as a result of the efficiency with which geological strata are attenuating contaminants.

Environmental Monitoring and Management – Action or Distraction?

Chris Dussek, Viridor Waste Management

In the PPC era of site management and operation, regulated operators have seen an unprecedented demand for the collection and management of environmental data arising from the 'permitted activities'. Yet the challenge to the operator has been more than simply adhering to basic schedules set out in permits, licences and planning permissions at any site. At a time when organisations are faced with an ever increasing volume of data, the requirement for timely, informative and meaningful interpretation of the data is critical, in order that appropriate actions can be undertaken by the Company in response to any monitoring event. Within a contemporary data management system, is it possible to strike a balance between prescriptive core data collection and flexible responsive monitoring? How can the tensions between risk management, legislative requirements and third party expectations be addressed and managed in a profession and consistent manner?

For the past two years, Chris Dussek has been the Environment Manager in one of the fastest growing waste management companies in the UK, and has been responsible for the delivery of contemporary environmental monitoring and management programmes across the Company's portfolio of facilities across the UK. Drawing of his experiences in change management within the Company, the presentation will consider who has benefited most from the changes implemented, and will consider what lies ahead for the waste management sector with regards to data management requirements in the foreseeable future.

Transport of Mecoprop through Mercia Mudstone and Oxford Clay Liners

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Mecoprop, a phenoxyalkanoic herbicide, is frequently found in leachate from UK municipal solid waste landfills. It is often chosen for consideration in landfill risk assessments because it is relatively mobile, and is designated a List I substance under the Groundwater Regulations 1998. However, little is understood about the processes that determine attenuation and transport of Mecoprop in landfill liners. Accordingly, a series of column tests was undertaken using a specially adapted triaxial cell apparatus to examine the transport of Mecoprop. Additionally, Bromide was used as a tracer and was assumed to be conservative. An analysis is presented of these breakthrough curves for transport through both Mercia Mudstone and Oxford Clay under varying pressure gradients. The most significant observation is that Mecoprop breakthrough occurred much sooner than predicted by the retardation factor derived from accompanying sorption batch tests.

Transport and Attenuation of Leachate in Unsaturated Sandstone

Adrian Butler, Department of Civil and Environmental Engineering, Imperial College London

Landfill leachate emanating from old “dilute and disperse” sites represents a potential (and in many cases actual) threat to the integrity of groundwater. However, in the UK, whilst there are a substantial number of unlined landfills sited on major aquifers, many of these are in locations where there is a substantial unsaturated zone. Thus, there exists the possibility for attenuation of the leachate prior to it encountering the water table. An understanding of the geochemical processes affecting the fate and transport of leachate contaminants will enable more comprehensive assessments of the potential risks and liabilities posed by such sites to be made.

Such an investigation has taken place at the Burntstump landfill, situated 8 km north of Nottingham (UK) and sited on an outcrop of Sherwood sandstone. The fine friable sand has been quarried since the 1960s and the excavated volume used to store municipal waste. Filling at the site commenced in the mid 1970s and originally was unlined. In 1978 the first of what was to become a series of boreholes was installed within an area of roughly 5 m radius over one of the original waste cells. Cores of the waste and underlying sandstone were extracted and analysed for a range of physical and chemical parameters. The most recent set of analyses were obtained in 2000. The series of investigations therefore provide an important record of leachate migration and modification through the unsaturated zone for over twenty years.

The progression of the leachate front is clearly delineated by the chloride concentration profile with an average velocity of 1.6 m yr^{-1}. An interesting feature of the sequences of porewater concentration profiles is the sharp leading front of the Cl plume, indicating that little solute dispersion is occurring. This is due to the relatively uniform particle size of the sand matrix combined with the low moisture content, which has greatly constrained the available pore sizes in which flow occurs. A marked reduction in the mass of the chloride plume has been observed over the last 13 years. Analyses of core sample taken in 2000 show that the Cl profile has continued to lose mass and has now also separated into two peaks. The leading peak was located at a depth of 36 m below ground level (28 m below the base of the landfill) and in line with model predictions. The trailing peak was at a depth of 27 m bgl and was associated with a 0.3 m layer of marl and clay bands. Thus there is an indication that the changes in chloride mass are possibly due to the effects of heterogeneity, although other processes which could account for chloride removal from solution are also under consideration.

The location of the TOC front up to 1992 was commensurate with that of Cl, indicating no effective retardation. This is consistent with the very low levels of organic carbon present in the sandstone. However, marked reductions in contaminant mass (substantially greater than those of Cl) have been observed. Analyses of volatile fatty acids have indicated a progressive breakdown of VFA components leading to simpler products so that by 1991 the dominant component was ethanoic acid (56% by mass). By 2000 the entire leading front of the TOC was absent. TOC was only found to be present at relatively low concentrations (~100 mg l^{-1}) above the marl/clay band. Analyses of gas concentrations at the site have indicated that there has been a change in the redox potential in the volume of contaminated unsaturated sandstone below the waste cells during the last 10 years. With predominantly anaerobic conditions giving way to aerobic. This change appears to be related to the introduction of a landfill gas extraction system at the site, which has resulted in atmospheric oxygen being drawn into the underlying environment. Although the sandstone is relatively inert (CEC ~ 2 meq 100 g^{-1}), retardation of the ammoniacal nitrogen is evident. The retardation coefficient is about 4 giving a linear equilibrium partition factor K_d of 0.15 cm^3 g^{-1}. However, ammonium attenuation appears to be very low, if at all.

Geochemical modelling of the Burntstump data using PHREEQC has provided further insights into the chemical interactions between the leachate and the underlying Sherwood Sandstone. The Burntstump leachate source was conceptualised as an acidic solution moving down a one-dimensional column of sandstone. Step-wise organic acid degradation and gradual pH buffering of pore waters via dolomite dissolution were successfully simulated using kinetic reactions. Cation exchange using a simple equilibrium exchange model allowed for ammonium and potassium ion retardation of a similar order of magnitude to that at Burntstump. Simulations suggested that large amounts of carbonate re-precipitation occurred behind the plume's acidic front. However, the model also showed "over buffering" (i.e. pH > 9.5) in this region, which is thought to be due to difficulties in reproducing the exact chemistry of the leachate source. Overall, the analyses indicate that 30 m of unsaturated Sherwood sandstone has the potential to substantially attenuate the impact of MSW leachate emanating from a moderately wet landfill on the underlying groundwater. This has important implications both in terms of groundwater protection and the environmental liabilities for waste operators and landfill site owners at similar sites.

Assessing the Risks from Hydraulically contained Landfill Sites

Hugh Potter, Environment Agency and Institute for Research on Environment and Sustainability (IRES), Newcastle University

At around 200 operational and closed non-hazardous waste landfill sites in the UK, the natural groundwater level is above the base of the landfill. Often the only barrier protecting groundwater from polluting leachate is an artificially constructed liner that may be vulnerable to degradation and damage. About 40 to 50 of these landfills are operated on the “hydraulic containment” principle whereby leachate is pumped out to depress the leachate level in the waste to below the external groundwater level. This creates a hydraulic gradient that draws groundwater into the landfill by advection and so prevents the outward advective movement of leachate. However contaminants can also move out of the landfill by diffusion. This can be an important process in hydraulic containment sites since low permeability liners lead to very low advective flow of groundwater into the landfill, and the diffusive flux may be relatively high.

The Groundwater and Landfill Directives require hydrogeological risk assessments to be carried out to demonstrate that there will be no unacceptable risk to groundwater throughout the whole lifecycle of the landfill. For most landfill sites, the Environment Agency’s LandSim model is preferred, however this is not appropriate for sub-water table sites. An alternative spreadsheet based tool has been developed to help assess the impact on groundwater from hydraulic containment landfills. This allows the diffusive flux from these sites to be estimated depending on the landfill geometry. Diffusion, advection, dispersion, retardation and decay processes are included as appropriate.

In landfills with mineral liners, lowering the liner hydraulic conductivity encourages outward diffusion of contaminants. However, increasing the hydraulic conductivity (or the leachate-groundwater head difference) leads to greater volumes of leachate being generated and potential stability issues. Organic contaminants are expected to readily diffuse through geomembrane liners. Since inward advective flow through an intact geomembrane is minimal, outward diffusion of organic compounds through a defect-free geomembrane liner is greater than through a composite liner with many defects.

This paper will discuss the technical issues pertinent to hydraulic containment landfill sites including the spreadsheet tool and guidance published by the Environment Agency. Diffusion can cause significant fluxes of contaminants out of landfill sites, even against an inward advective flow of groundwater. These sites therefore have the potential to cause pollution if they are not located, designed, constructed and operated in an appropriate manner.

Fail-safe Engineering: Towards Sustainable Landfill

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The issue of landfill sustainability has been, and will continue to be, an issue that the waste industry needs to address as the recognition of the time taken for equilibrium to be achieved between wastes deposited and the wider environment continues to be assessed as centuries rather than decades. A research contract has been completed, funded by DEFRA under the Waste and Resources Evidence Programme, to examine a parallel theme – that of assessing the engineering and management options that might ensure that failure of the engineering containment system of a landfill does not mean wholesale environmental damage.

The research work builds on research contained in the Equilibrium Project, the results of which have been previously published (Hall et al, 2005). However, the earlier work looked primarily at the groundwater impacts from inorganic species contained in the leachates of processed/treated MSW residues. This project builds on the one of the key findings of the earlier work in that landfill sites will need to achieve a hydraulic equilibrium as well as a chemical equilibrium. Our current management regime for the majority of landfills in Europe is to fill small cells to reduce leachate production and to cap sites once they are full. Couple this with the requirements to maintain a small hydraulic head on the basal liner and we end up with a site that is in the greater part unsaturated. It seems quite conceivable that at some point in the future, when the leachate reaches some specific quality standard, all management controls can be removed from the site. The consequence of doing this is that the leachate level will rise within the waste, and resaturate wastes that have been unsaturated for decades/centuries. Leakage will increase dramatically, but there is also likely to be a short term increase in the concentrations of contaminants within the leachate. Overtopping of the containment system is quite possible with a subsequent risk to surface water quality without the benefits of the purifying powers of the soil inherent in any discharge to groundwater.

This research project has modeled the hydraulics via the HBM model (McDougall, 2007)
and fate and transport of resultant leakage (using GoldSim) to both groundwater and surface water (the latter looking solely at the overtopping issue). The effects of site geometry as well as different waste streams (MSW, Mechanical Biological Treatment Residues and Incinerator Bottom Ash), have been investigated, along with a number of options to mitigate against the consequences of premature site closure.

Do More Detailed Hydrogeological Risk Assessment Tools Support Better Regulation of Landfill?

Alan Herbert *& Kim Gray, ESI Ltd*

Quantitative hydrogeological risk assessments have been required for licensing and, more recently, permitting landfill sites for many years. These have become quite familiar and there are well established templates and procedures for constructing such risk assessments so as to comply with the Environment Agency's requirements. It is worth remembering however that landfill sites are amongst the most complex hydrogeological problems that modellers will face. They combine engineered and natural low permeability barriers with strong chemical environments. These lead to complex three-dimensional chemical transport pathways with, again, complex reactive transport processes along the risk pathways.

The new Landfill Regulations require very high levels of containment that lead to the potential lifetime over which the site continues to pose a potential risk being very long. Indeed, the Environment Agency promote a timescale of assessment of thousands of years – longer than the timescale of the human historical record!

When the requirement for quantitative risk assessment first arose, simplified representations of the pollutant linkage, involving representations of the pathways along which contaminants might travel, were developed and simple software tools developed to quantify the risks. These were used to compare different approaches to landfill design and give confidence that the proposed facility would not give rise to unacceptable risks.

A recent trend has been to increase the level of detail in these models, as exemplified by the recent release of Landsim 2.5. We argue that the additional complexity inevitably only addresses a small part of the grossly simplified model. In so doing it leads to much less transparent models that are harder to use, and gives a misleading impression of the capability of these tools to represent the detail of the conceptual model. It is important that the results are used appropriately as a guide to judgement and that the site operators and regulators remember how simplified and uncertain these models really are over the timescales of appraisal.

An additional concern is the level of verification and validation that has been applied to the more sophisticated models. Numerical approximations have inevitably been used and simplifications and methods that were appropriate for simple steady-state representations of the pollutant linkages are less robust when attempting to represent the evolution of the system over time. These shortcomings are probably not always obvious to the user of these models, again making it more difficult, not less, to exercise sound judgement in interpreting the results of such complex quantitative hydrogeological risk assessments.

Modelling of Liquid and Gas Transport in Wastes – Optimising an Aerobic Treatment Process

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The liquid phase in a landfill plays a very important role in the bio-chemical processes taking place in the waste material contained in the landfill, and in the way in which a landfill reacts with its environment. Commonly known as leachate in the context of landfills the liquid phase is a complex aqueous solution consisting of water and a variety of dissolved chemical compounds. At any location in a landfill the condition, properties and behaviour of the liquid phase is determined by the hydrology and hydraulics of the landfill material, topics that are not particularly well understood, and which are the subject of wide ranging research programme at the University of Southampton.

Over the past ten years the Waste Management Research Group at the University of Southampton has developed a landfill degradation and transport model known as LDAT. The objectives of the LDAT landfill model are to assess the consistency of landfill datasets and to extrapolate data, whilst exposing areas where we need to improve our understanding of landfill systems. Specifically LDAT is aimed at understanding how wastes degrade in landfills, and how we can intervene to accelerate the bio-chemical stabilisation of wastes.

LDAT models the transport and bio-chemical behaviour of the solid, liquid and gas phases of waste contained in a landfill.

The structure of LDAT will be described and details will be given of the compounds and degradation chemical pathways that it contains. Particularly attention will be given to the way in which LDAT accommodates the liquid and gas phases and is able to highlight the issues raised by our lack of knowledge of some aspects of the hydrology and hydraulics of the liquid phase in landfills.

An example of using the model to support an aerobic field experiment will be given. The experiment involves aerating a 6m wide, 30m long, 3m deep volume of domestic waste by pumping air in through the base, whilst measuring the temperature and moisture content at positions within the waste. The objective of the model study is to develop insight into the aerobic treatment process to assess the extent to which the application of aeration may be used to control the temperature and moisture content so that the degradation and nitrogen removal rates can be optimised.
